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As of January 1, 1996, chlorofluorocarbon (CFC) refrigerants CFC-11 and CFC-12 can no longer be produced in the United States. It is estimated that as many as 60,000 or 74% of CFC chillers in service today in industrial, commercial, and institutional buildings still use the "banned" refrigerants. In addition, most of the Navy's centrifugal chillers also use these refrigerants.

In May 1994, the Naval Facilities Engineering Command dictated (NAVFAC Notice 5090) that all shore-based Navy Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) equipment containing Class I Ozone Depleting Substance (ODS) be replaced or converted by December 41, 2000. Equipment conversions must utilize an approved refrigerant - one with an Ozone Depleting Potential (ODP) of 0.05 or less.

The decision to eliminate CFC refrigerants at Navy facilities must begin with a CFC management plan. The plan should address items such as, reducing leakage in existing CFC systems, HVAC maintenance personnel training standards, and retrofitting or replacing CFC refrigerant-using equipment. The decision to retrofit or replace CFC refrigerant chiller must involve the chiller manufacturer. Manufacturers will (often at no cost) evaluate your existing cooling system, determine the most appropriate retrofit method, and determine which option is the most economical choice.

14. SUBJECT TERMS

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TechData Sheet

Naval Facilities Engineering Service Center
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TDS-2045-E&U **September 1997**

Centrifugal Chillers -- CFC Retrofit Versus Replacement

As of January 1, 1996, chlorofluorocarbon (CFC) refrigerants CFC-11 and CFC-12 can no longer be produced in the United States. It is estimated that as many as 60,000 or 74% of CFC chillers in service today in industrial, commercial, and institutional buildings still use the "banned" refrigerants. In addition, most of the Navy's centrifugal chillers also use these refrigerants.

In May 1994, the Naval Facilities Engineering Command dictated (NAVFAC Notice 5090) that all shore-based Navy Heating, Ventilation, Air Conditioning and Refrigeration (HVAC&R) equipment containing Class I Ozone Depleting Substance (ODS) be replaced or converted by December 31, 2000. Equipment conversions must utilize an approved refrigerant - one with an Ozone Depleting Potential (ODP) of 0.05 or less.

Since the refrigerants can no longer be produced, continued use is becoming a problem. Experts in the HVAC&R industry and the U.S. Environmental Protection Agency (EPA) are surprised at the continued use of these chillers. Based on the survey conducted by the Air Conditioning and Refrigeration Institute (ARI), experts expected an additional 9%, approximately 4,500 units, to be converted or replaced by January 1, 1997. The refrigerant phase-out may contribute some economic advantages in addition to environmental benefits. Replacing old, inefficient chillers with new, high efficiency chillers can reduce operation and maintenance (O&M) costs and eliminate the need for the extremely scarce and costly CFC refrigerants.

The delay in retrofitting or replacing CFC chillers may stem from confusion of how to phase out CFC refrigerants in existing chillers, as well as a lack of capital funds for retrofits and replacements. The continued use of these systems is placing a strain on the dwindling reserves of "banned" CFC refrigerants needed to support the unconverted chillers, and could result in price increases and delivery delays for the scarce refrigerants. Given the present situation, Naval facilities must begin to look for the most economical approach to meeting the CFC phase-out requirement. This TechData Sheet (TDS) provides insight into determining if retrofitting or replacing is the best option. It provides general analysis requirements, refrigerant alternatives for retrofit and replacement of CFC-11 and CFC-12 refrigerants, discusses capacity and efficiency effects on retrofit projects, and provides a case study which investigates a common scenario.

CFC Replacement Refrigerants

Class I ODS, present in most CFC centrifugal chillers, includes CFC-11 and CFC-12. Although the Class I ODS list contains more CFC refrigerants, only CFC-11 and CFC-12 are discussed in this TDS due to their prevalence in centrifugal cooling. Table 1 provides Class I ODS information, including a CFC and retrofit refrigerant summary of general characteristics. Table 2 provides a list of acceptable replacement chiller refrigerants and other refrigerant substitutes. Additional substitute refrigerants may be acceptable for CFC-12 centrifugal chiller replacement under the EPA's Significant New Alternative Policy (SNAP), but the most common CFC substitutes for both CFC-11 and CFC-12 are shown in Table 2.

Hydrochlorofluorocarbons (HCFC) and hydrofluorocarbons (HFC) are presently environmentally acceptable refrigerants. Under the Clean Air Act and in accordance with the Montreal Protocol, HCFC-123 will be available for use in new chillers until 2020 and in existing chillers until 2030. Similarly, HCFC-22 will be available for use in new machines until 2010 and in existing machines until 2020. HFC-134a, unlike HCFC, does not contain chlorine and poses no ozone-depletion threat; therefore, no ban is proposed for HFC-134a.

Retrofit Versus Replacement

Before retrofitting or replacing an existing chiller, the facility should investigate if any cooling load reduction projects exist or if the chiller has been oversized to meet building functional

Table 1. CFC Centrifugal Chiller Retrofit Refrigerant Summary

CFC Type	ODP	Atmospheric Life (yrs)	Retrofit Refrigerent	ODP	Atmospheric Life (yrs)
CFC-11	1.0	64	HCFC-123	0.016	1.4
CFC-12	1.0	108	HFC-134a	0.0	13

Note: ODP - Ozone Depleting Potential refers to the destructiveness of the compound, compared to that of CFC-11, which has a value of 1.0.

Table 2. CFC Centrifugal Chiller Replacement Chiller Options

	Centrifugal Chillers	
Substitutes	CFC-11	CFC-12
HCFC-123	X	X
HCFC-22	X	X
HFC-134a	X	X
Ammonia/Water Absorption	X	X
Water/Lithium Bromide Absorption	X	X

changes. Lighting retrofits, building envelope modification projects, and air handling system efficiency improvements can change the cooling capacity of the facility. Facilities must evaluate if oversized chillers can be retrofitted or replaced by an appropriately sized chiller. The existing chiller can often be retrofitted to reduce capacity and potentially increase efficiency. These capacity changes can also reduce retrofit costs and future preventive maintenance costs. Furthermore, the reduced capacity will decrease the needed replacement chiller tonnage and therefore reduce the purchase and installation cost of a new chiller.

Age of the existing chiller should not be the only factor used to determine if the chiller should be replaced or retrofitted, but it should be considered when planning for CFC compliance. Centrifugal chillers using CFC refrigerants purchased within the last 10 years are good candidates for retrofit. Chillers in this age range operate at fairly high efficiency and much of their useful life remains. Often a simple or engineered conversion (explained below) will result in minimal if any reduction in capacity and efficiency. Retrofit of these newer chillers will usually result in the most economic approach to eliminating CFC usage. In some cases, it may be more cost effective to replace even these newer chillers. Detailed retrofit costs from the manufacturer should be compared with replacement costs before proceeding. Centrifugal chillers purchased over 20 years ago have probably reached or exceeded their useful life and should be replaced. Also, chillers of this age have lower operating efficiencies than new, high efficiency chillers. Estimated energy consumption per ton for centrifugal chillers over the past 20 to 30 years are provided in Table 3.

Table 3. Estimated Centrifugal Chiller Energy Consumption per Ton

Centrifugal Chillers	kW/ton
Over 20 years old	0.80 to 1.0
Between10 to 20 years old	0.65 to 0.80
Present	0.49 to .65

Note: kW/ton values are energy consumption per ton at Air Conditioning and Refrigeration Institute (ARI) standard conditions. Chiller efficiencies will degrade over time.

Deciding if retrofit or replacement is the most appropriate and cost effective choice is the most difficult for centrifugal chillers in the 10- to 20-year old range. The decision is site specific and depends on maintenance history, needed capacity, and accessibility for removal. The following sections provide: (1) general retrofit and replacement guidelines which will assist a facility in making the most appropriate choice, and (2) a hypothetical case study with economic analysis.

A category of chillers for special consideration is small centrifugal chillers, under 400 tons. Major manufacturers have plans to phase this type of chiller out of their product line and replace them with rotary screw models. When evaluating these smaller centrifugals, keep in mind that many manufacturers have discontinued these models and replacement parts are increasingly difficult to find. It is also likely that the manufacturer will not offer a retrofit package, depending on the age of the chiller. Regardless, the first step in the decision is to contact the manufacturer and determine if a retrofit is available. Unless the chiller is very new, the best option is to replace it.

Retrofitting CFC Centrifugal Chillers

Most CFC refrigerant chillers can be converted to use alternative refrigerants. Although these refrigerants are less efficient than the CFC refrigerants they replace, often retrofit options can curtail the reduced efficiency and potentially increase efficiency. The three options that follow meet EPA's CFC compliance issues but each facility must determine which option best meets their cooling and economic needs. This information is intended to provide general information regarding selection of the most appropriate retrofit option. When investigating these options, the chiller manufacturer should be contacted to evaluate the most appropriate retrofit option, evaluate capacity and efficiency changes, and provide economic analysis support.

Simple Conversion

A simple conversion involves converting only the materials which are incompatible with the new refrigerant. This option includes removal and replacement of seals and lubricants and can be implemented quickly and at a relatively inexpensive first cost (i.e., 20 to 30% of the cost of a new chiller (Ref 1)). Although this option eliminates the CFC refrigerant and is inexpensive to implement, it is often an inappropriate choice, because the new refrigerant reduces efficiency and full load capacity of the chiller. The amount of the reduction can be substantial and should be compared to the required capacity of the connected load. If the full load cooling capacity for the building cannot be reduced, then this simple retrofit cannot be implemented. In addition, according to Navy-wide energy reduction guidelines, it may be unwise to reduce the efficiency of the chiller, thus increasing energy consumption and ultimately, operating costs.

Engineered Conversion

The most popular option is the engineered conversion in which mechanical modifications are completed to minimize capacity and efficiency reductions. Mechanical modifications may include gear changes, impeller trimming, and orifice changes. The efficiency of chillers in the 10- to 20-year old range is typically good and proper mechanical modifications can result in only minor performance degradation. Often these modifications can be the most economical option when choosing to retrofit the existing chiller versus replacement. At a cost of approximately 40 to 60% of the cost of a new chiller (Ref 2), an economic analysis can prove this option to be the most cost effective alternative.

Driveline Conversion

To compensate for the lower efficiency of new refrigerants, chiller manufacturers have made great improvements to driveline components. Driveline conversions combined with reduced cooling capacity can lead to an increase in efficiency for retrofit chillers. A chiller conversion of this type would include motor and compressor replacement and new microprocessor controls. These improvements have a high cost (approximately 60 to 80% of the cost of a new chiller) and should be implemented only on high efficiency chillers 10 years old or less, since much of their useful life remains. Driveline conversion may be the most cost effective alternative for buildings with inconvenient chiller locations (where tearing down walls is necessary for removal) or unique configurations or applications exist.

Replacing CFC Centrifugal Chillers

Centrifugal chiller manufacturers have developed new product lines which utilize the non-CFC refrigerants and have made improvements to driveline components and control systems. Present chiller efficiencies (listed in Table 3) combined with low procurement and installation costs may prove that a new replacement chiller is the best alternative when compared to the retrofit options discussed above. Table 4 lists estimated procurement costs per ton for new centrifugal chillers.

Table 4. Estimated Centrifugal Chiller Efficiency and Cost per Ton

Tonnage Range	Chiller Efficiency	Cost per Ton
400 to 500	0.60	$205
	0.49 to 0.52	$310
500 to 600	0.60	$195
	0.49 to 0.52	$295
600 to 800	0.60	$190
	0.49 to 0.52	$285
800 to 1200	0.60	$170
	0.49 to 0.52	$265

Note: Information provided by the Trane Company. Values are estimates only.

Retrofit versus Replacement Example

The following example problem assumes that a cooling load analysis has been done and the existing chiller size is appropriate for the application and both the retrofit and replacement can be completed without any unique complications, such as extensive building or piping modifications.

An administrative building located in the Southeast requires 500 tons of cooling. The existing centrifugal chiller is approximately 15 years old, operating well, and would require a typical engineered conversion at a cost of 50% of a new chiller. The existing HVAC system is operating adequately and no modifications are needed if the chiller is replaced in kind.

Sample Calculations

1. Cooling Load Calculation

Occupancy schedule was assumed to be Monday through Saturday - 0600 to 1800, illustrated in Figure 1. Occupancy factors for each region are calculated and presented in Table 5.

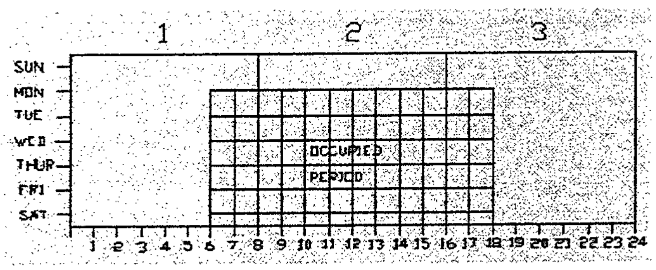

Figure 1. Building occupancy schedule.

Table 5. Regional Occupancy Factors

Region No.	Occupied Time (A)	Total Area (B)	Occupancy Factor (A/B)
1	6 x 2 = 12 hrs	7 x 8 = 56	0.2143
2	6 x 8 = 48 hrs	7 x 8 = 56	0.8571
3	6 x 2 = 12 hrs	7 x 8 = 56	0.2143

Example Hour of Occurrence Calculation

The example hour of occurrence calculation shown below is for May with a temperature range of 55/59 (bin data selected from NAVFAC Manual P-89 (Ref 3)). Table 6 provides total month/hour of occurrence values. It was assumed that no cooling was provided for temperatures below 55 degrees, and therefore, hours of occurrence below this temperature are not included in Table 6.

$$0.2143\ (40) + 0.8571\ (6) + 0.2143\ (21) = 18.2 \text{ hours}$$

2. IPLV Calculations

The Integrated Part Load Value (IPLV) is the efficiency measured in kW/ton, averaged over several operating points. The formula for IPLV is:

$$\text{IPLV} = \frac{1}{\frac{A1}{A} + \frac{B1}{B} + \frac{C1}{C} + \frac{D1}{D}}$$

where A1, B1, C1, and D1 are the percent of time, in a year, that the chiller operates at a given percent load. A, B, C, and D are the kW/ton values at the corresponding percent loads.

IPLVs and kW/ton values for each chiller, corresponding to the percent loads, are provided in Table 7.

Table 7. Percent Load Efficiencies and IPLV Values

Values	Existing Chiller	New Chiller
% Time at % Loads	0.24, 0.31, 0.33, 0.12	0.24 ,0.31, 0.33, 0.12
% Load Eff. (kW/ton)	1.05, 0.95, 0.85, 0.75	0.76, 0.68, 0.60, 0.52
IPLV	0.91	0.64

Table 6. Monthly Hours of Occurrence

			Monthly Hours of Occurrence											
% Time (hrs)	% Load	Temp	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
12%	100	95/99						1.7	1.7	2.6				
(331)		90/94					4.3	9.6	22.7	21.0	4.3			
		85/89				5.1	17.4	44.4	85.5	73.5	34.1	2.6		
33%	75	80/84			1.7	14.8	45.0	79.5	87.0	85.9	73.1	17.4	1.7	
(880)		75/79	0.9	1.7	7.9	35.6	68.1	74.4	73.9	77.1	73.3	46.7	11.4	2.6
31%	50	70/74	6.0	7.7	16.3	43.1	69.0	54.0	40.0	48.0	64.3	67.3	27.9	11.4
(847)		65/69	14.6	14.6	29.8	58.5	52.7	30.0	6.4	10.7	36.4	71.4	45.9	21.4
24%	25	60/64	22.1	26.1	44.4	56.8	34.7	9.2	1.7	1.3	15.2	51.2	55.1	30.2
(656)		55/59	30.6	29.6	52.5	42.0	**18.2**	3.6	0.2		5.1	30.9	53.1	41.8
Totals			74	80	153	256	309	306	319	320	306	288	195	107
Annual Total			2,713											

Table 8. Input Variables

Variables	Existing Chiller				New Chiller			
Chiller Size	500 tons				500 tons			
Annual Hours of Operation	2,713 hours				2,713 hours			
Maximum % Peak Load	90%				90%			
Chiller Efficiency (Peak/IPLV)	0.75/0.91				0.52/0.64			
Parasitic Loads	0.12 kW/ton				0.10 kW/ton			
Chiller Cost	$ 148/ton				$295/ton			
Installation Cost	Included				$10,000			
Maintenance Cost	$0.01/ton-hour				$0.005/ton-hour			
Monthly Peak Cooling Load* (% of Maximum Peak)	Jan	45	Feb	55	Mar	65	Apr	75
	May	80	June	85	July	100	Aug	100
	Sept	85	Oct	70	Nov	60	Dec	50
Electric Utility Rates	Energy Cost = $0.030/kWh				Demand Charge = $12.65/kW			

*Note: Maximum peak cooling loads based on hour of occurrence data.

3. Economic Analysis

The variables in Table 8 were used to compare the economics of retrofitting the existing chiller versus replacing it with a new high efficiency centrifugal chiller. The numbers below apply only to this sample; actual values for specific sites will vary and must be investigated.

1) Electric Peak kW = Rated Cap x Peak Eff x Max % of Peak Retrofit Chiller = 500 tons x 0.75 kW/ton x 0.90 = 337.5 kW

   New Chiller = 500 tons x 0.52 kW/ton x 0.90 = 234 kW

2) Billed Demand = (Electric Peak kW x % of Max Peak) + (number of tons x Parasitic Load)
   (Example for March - See Table 9 for complete year)

   Retrofit Chiller = (337.5 kW x 0.65) + (500 tons x 0.12 kW/ton) = 279 kW or $3,529/Mn

   New Chiller = (234 kW x 0.65) + (500 tons x 0.10 kW/ton) = 202 kW or $2,555/Mn

3) Energy Costs = Rated Capacity x Annual Hours x IPLV x Energy Cost

   Retrofit = 500 tons x 2713 hours x 0.91 x $0.030/kWh = $37,032/Yr

   Retrofit Parasitic = (500 tons x 0.12 kW/ton) x 2,713 hours x $0.030/kWh = $ 4,883/Yr

Retrofit	37,032
Retrofit Parasitic	4,883
	$41,915/Yr

   New = 500 tons x 2,713 hours x 0.64 x $0.030/kWh = $26,045/Yr

   New Parasitic = (500 tons x 0.10 kW/ton) x 2,713 hours x $0.030/kWh = $ 4,070/Yr

New	26,045
New Parasitic	4,070
	$30,115/Yr

4) Maintenance Cost = Annual Hours of Operation x number of tons x $/ton-hr

   Retrofit Chiller = 2,713 hours x 500 tons x $0.01/ton-hr = $13,565/Yr

   New Chiller = 2,713 hours x 500 tons x $0.005/ton-hr = $6,783/Yr

5) Total 1st Year Costs = Energy Cost + Demand Cost + Maintenance Cost

   Retrofit Chiller = $41,915 + $46,275 + $13,565 = **$101,755/Yr**

   New Chiller = $30,115 + $33,347 + $6,783 = **$70,245/Yr**

   New Chiller Cost Savings = $101,755 - $70,245 = **$31,510/Yr**

6) Simple Payback = New Chiller - Retrofit Chiller Cost/Cost Savings = $157,500 - $74,000/$31,510 = **2.65 Years**

In this example, installing a new centrifugal chiller would be more cost effective than retrofitting the existing chiller. The issue of chiller replacement is one of environmental compliance, mandated by law for ozone protection, not energy conservation. The example shown would not be eligible for energy project funds.

Table 9. Yearly Demand Summary

Billed Demand		Existing Chiller		New Chiller	
Month	Demand Charge ($/kW)	Demand (kW)	Demand ($)	Demand (kW)	Demand ($)
Jan	12.65	212	2,682	155	1,961
Feb	12.65	246	3,112	179	2,264
Mar	12.65	279	3,529	202	2,555
Apr	12.65	313	3,959	226	2,859
May	12.65	330	4,175	237	2,998
June	12.65	347	4,390	249	3,150
July	12.65	398	5,035	284	3,593
Aug	12.65	398	5,035	284	3,593
Sept	12.65	347	4,390	249	3,150
Oct	12.65	296	3,744	214	2,707
Nov	12.65	263	3,327	190	2,404
Dec	12.65	229	2,897	167	2,113
Total			$46,275		$33,347

Conclusion

The decision to eliminate CFC refrigerants at Navy facilities must begin with a CFC management plan. The plan should address items such as reducing leakage in existing CFC systems, HVAC maintenance personnel training standards, and retrofitting or replacing CFC refrigerant-using equipment. The decision to retrofit or replace CFC refrigerant chillers must involve the chiller manufacturer. Manufacturers will (often at no cost) evaluate your existing cooling system, determine the most appropriate retrofit method, and determine which option is the most economical choice.

NFESC is available to perform retrofit versus replacement analysis or any chilled water system analysis for Naval activities on a reimbursable basis. If you would like more information on CFC issues or chilled water systems, contact **Mr. Darryl Matsui at (805) 982-3487, DSN 551-3487, or *dmatsui@nfesc.navy.mil.***

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